The Use of GIS in Identifying Risk of Elevated Blood Lead Levels in Australia

Lisel A O'Dwyer, PhD*
National Key Centre for Social Applications of GIS, School of Geography, Population and Environmental Management, Flinders University, Adelaide, South Australia, Australia

Abstract

Unlike in the United States, environmental lead in Australia and the dangers it poses to small children are generally not regarded as a major public health issue. However, the results of a recent national survey, which found that only 7.3% of children under 5 years old had blood lead levels (PbB) over 10 micrograms per deciliter, are questionable due to insufficient attention given during sampling to the geography of urban housing and risk factors. Geographic information systems (GIS) can address such variation, and based on the spatial distributions of known risk factors, can identify areas, streets, and even individual dwellings with a high probability of high environmental lead levels. Predictions can then be validated with atomic absorption spectrometry analysis of blood or dust samples. Preliminary results based on GIS analysis of a metropolitan digital cadastral database and its associated housing data and the spatial distribution of relevant entities, such as childcare centers, suggest that the prevalence rate of elevated PbB in one major Australian city is significantly higher than was reported in the national survey. This analysis will form the basis for a model predicting the presence and risk of environmental lead for any city. It also offers a means of targeting further investigation of lead exposure, using small-area census data to estimate the number of children at risk more accurately, and selecting areas for future sample surveys. Developing a cost-efficient and accurate method of modeling lead exposure risk to children is a task to which GIS is clearly well suited.

Keywords: pediatric blood lead levels, risk, urban, socioeconomic status

Introduction

The issue of elevated blood lead levels (PbB) has not received the detailed attention in Australia that it has in the United States. There are many reasons for this. One is the perception among health authorities and the lay public that environmental lead is not a major concern, especially in relation to other preventable and more manageable childhood illnesses. Despite this perception, it has been suggested that lead poisoning is probably more common than most of the diseases routinely screened for in childhood (1). Another reason is the political difficulty in addressing the issue of lead, especially where the lead industry is important to the local economy, as is the case in South Australia.

While Australia has the same risk factors for elevated PbB as the United States, there may be some differences between the two countries in the relative importance of these factors. In Australia, it has taken eight decades for the lead content in paint to be reduced in increments to its current levels, though the danger was recognized in the

*Lisel O'Dwyer, National Key Centre for Social Applications of GIS, Flinders University School of Geography, Population and Environmental Management, GPO Box 2100, Adelaide, South Australia 5001 AUS; (p) 61-08-8201-2969; (f) 61-08-8201-3521; Email: lisel.odwyer@flinders.edu.au

Australian state of Queensland at the turn of the century. (Most Queensland housing is painted timber, thus maximizing the amount of lead paint in children's environments). The lead content of paint was not reduced in the United States until 1978 (2). On the other hand, the phasing out of leaded gasoline in Australia began in 1986, but its sale was made illegal in the United States in 1976 (3). In 1996, 38% of Australian vehicles still used leaded gasoline, while 45% of vehicles in the state of South Australia still used it. Many households with these vehicles are of low socioeconomic status and low income, and cannot afford to purchase and run later-model cars. People in lower-socioeconomic-status households are also more likely to work in industries involving and handling lead. It should be noted that South Australia's economy has been depressed in relation to the other Australian states for several decades and that South Australia has a strong base in manufacturing and light and heavy industry. The only Australian state that has a higher rate of leaded gasoline usage than South Australia is the economically depressed state of Tasmania. South Australia was also the last state to achieve the recommended lead level of 0.2 milligrams (mg) per liter for "unleaded" gasoline in October 1996 (4).

While there may be differences in the relative importance of the different sources of lead between Australia and the United States, in terms of previous findings and outcomes, there appears to be little difference between the sources of elevated PbB per se.

Lead is both a health problem and a social problem. As an industrial, urbanized country, Australia is no stranger to the known risk factors such as old paint in older housing, residential proximity to industries using lead, and household cleanliness. Many other lead risk factors involve individual behavior, such as hobbies involving lead, a child's tendency toward pica, and nutritional status. However, the literature to date has shown that a great deal of the lead involved in childhood lead poisoning comes from a child's environment. The source and distribution of this lead is thus beyond the control of individual households and parents. The main source of ingested lead in urban residential areas is usually paint in older housing. More than 3.5 million houses in Australia were built before 1971, when paint typically had high levels of lead. In general (though there are variations between the states), Australian paint contained up to 50% lead until 1950, when lead in paint was reduced to about 10%. The concentration was further reduced to about 1% in 1970, to 0.25% in 1992, and then to 0.1% in December 1997.

The literature generally agrees that the age of housing is a good indicator of the presence of old (leaded) paint. It has been found, for example, that Canadian children living in homes built in or before 1945 had an average PbB 62.3% higher than that of children living in homes built since 1975 (5). Australia's National Survey of Lead in Children (NSLIC) (6) also found a relationship between age of housing and PbB, even though the data for house age were based on estimates by interviewers and respondents rather than official sources (3). Even where children do not reside in a dwelling likely to have high levels of environmental lead, it is still important to identify such dwellings. In some cases children's elevated PbB are derived not from their own residence but from other residences in their community (7). Some dwellings are also contaminated by lead paint in adjoining dwellings via airborne and mechanical transport (8).

The status of the lead problem in Australia is difficult to ascertain. No direct comparisons between the United States and Australia are available. Prevalence rates for

PbB in the United States are based on the 1-to-5 age group, while the NSLIC—the only large-scale survey of PbB in Australia—examined children aged 1 to 4. Moreover, the use of mass screening programs in the United States over many years makes it possible to calculate reliable prevalence rates. Australia does not have any ongoing screening programs at all, except in the South Australian lead smelter town of Port Pirie. With these caveats in mind, however, the prevalence of elevated PbB (0.49 micromoles per deciliter [μmol/dL] or 10 micrograms per deciliter [μg/dL]) among 1- to 4-year-olds in Australia was found to be 7.3%. This represents approximately 75,000 children. The prevalence rate for American children in 1994 aged 1 to 5 is 8.9% (9). The finding that the prevalence rate in Australia was only 7.3% meant that the prevalence of elevated PbB was much lower than the Australian target prevalence of 10% by 1998, which was set in 1993. Some Australian health authorities have treated the low prevalence of elevated PbB in Australian children as a sign that there is no need to act to prevent lead exposure. Yet it has been shown that one-quarter of children within a 10-kilometer radius of the Sydney city center had elevated PbB in 1995 (10), as did a quarter of children in a working-class area in Perth, Western Australia, in 1994 (11).

There are clear social processes that result in excessive exposure to lead. The link between gentrification and childhood lead poisoning is supported by several studies that have found that the highest levels of blood lead are among children from the higher social strata, although the prevalence rate is higher among the lower-socioeconomic-status groups (12). The NSLIC found that most children with elevated PbB were socially disadvantaged (3), although an American survey found that 30% of urban infants (aged up to 1 year) with high socioeconomic status had PbB over 10 μg/dL (13). Although other studies agree that lead poisoning is found in all types of communities, it has been found that children in lower-socioeconomic-status areas were 7 to 10 times more likely to have lead poisoning (14). It is also significant that many of the households undertaking renovation of older housing (and who live in older housing either because of the price attraction of older inner-city housing or the investment potential of older housing in more upmarket areas) are young couples, including pregnant mothers and couples with young children. It has been observed that "renovation tends to impact on the most sensitive population" (8).

The fact that lead poisoning continues to occur in Australia shows that it is still a problem. The risk factors for lead poisoning are well known but research identifying the precise locations of these factors has yet to be undertaken in Australia. In the absence of blood testing—which measures only recent ingestion, not long-term exposure—other researchers have attempted to use questionnaires to predict elevated pediatric PbB. Results have shown the questionnaires to be not much better predictors than chance (13,15–18). There is a need to develop an alternative method of identifying children at risk. Because we are unable to identify the locations of individuals, the next best option is to identify precise areas that are likely to have hazardous levels of environmental lead. This is a task to which GIS appears well suited, given its capacity to integrate and query a variety of different datasets on a precise spatial basis. Some studies (19,20) that have used coarse spatial units (namely postcodes or local government areas [LGAs][1]) to examine the spatial distribution of PbB suggest that geographic location is

[1] An LGA is the lowest level of government in Australia, corresponding with the US county.

not of significant predictive value, but the small body of American research using GIS suggests otherwise (21–25).

It is obvious that the use of mass screening programs like those practiced in the United States would be a major expense for the Australian health system. Yet there are variations, spatial patterns, and concentrations of lead risk factors, and thus in elevated PbB, that might make targeted programs worthwhile. Hence the use of geographic information systems (GIS) in examining this public health problem. GIS technology has an important role to play in identifying the areas most likely to have high environmental lead levels—even though the prevalence of elevated PbB may be low in aggregate terms, these areas do exist. Random sample surveys have been useful in identifying the risk factors, and have shown that many of these risk factors have a characteristic spatial distribution or locational element. We may not need GIS to identify low-socioeconomic-status areas, but GIS enables us to identify individual addresses within those areas. It can also identify high-risk dwellings that may be nestled within an apparently low-risk area.

Risk is a two-dimensional concept, involving, first, the possibility of an adverse outcome and second, uncertainty over the occurrence, timing, and magnitude of that adverse outcome (25). If either is absent, then there is no risk. In the case of environmental lead, the presence of known markers or indicators shows there is a possibility of an adverse outcome. Whether lead poisoning actually occurs depends, of course, on the presence of children, while its timing and magnitude depend on a number of less readily measured factors such as the amount of time spent in the hazardous location, nutritional status (particularly iron, zinc, calcium, and fat intake), hand-to-mouth behavior, and the frequency and efficacy of household cleaning and vacuuming. The pathways by which lead enters the human body are undeniably complex, but it is nevertheless useful to consider using the presence of lead indicators and their spatial distribution as one way to estimate risk.

Method

Selection of Case Study Areas

For several reasons, South Australia is a useful area for a case study to demonstrate the use of GIS in identifying areas at risk for high environmental lead. According to the NSLIC, South Australia has the second highest mean PbB in the country (the Northern Territory has the highest level, but this is based on fewer than 20 cases) (6). South Australia's capital city of Adelaide is a relatively small city (1 million people), thereby facilitating travel for fieldwork and minimizing study costs. Another reason to select Adelaide is that networks already exist between Flinders University's Key Centre for Social Applications of GIS and relevant government and university departments. Figure 1 shows the locations of Adelaide and South Australia.

The original aim of this study was to examine the entire city. However, it was found that the database management system simply did not have the capacity to store all of the data required for the whole metropolitan area. Thus it was decided to select two LGAs as pilots with a view to extending the analysis to the whole city, one LGA at a time, after the methodology was established. (The Adelaide metropolitan area has

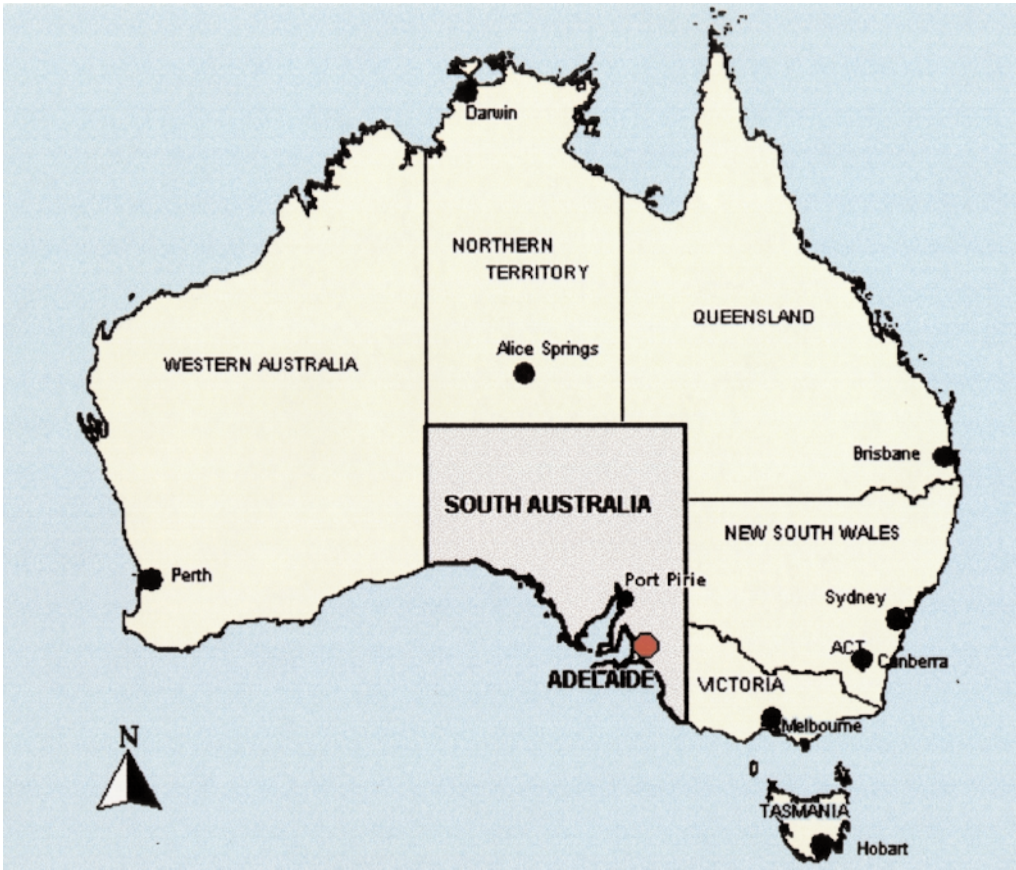

Figure 1 Location of study area in Australia.

approximately 30 LGAs, which vary in their level of heterogeneity with respect to socioeconomic status and land use.)

The two LGAs selected as case studies are Port Adelaide-Enfield LGA and Mitcham LGA (Figure 2). Both areas are located at similar distances from the central business district and have similar urban development histories, but have completely different socioeconomic profiles (Figure 3). They were selected because there is significant socioeconomic and housing type variation within as well as between them, so using them demonstrates the ability of the GIS to target specific small areas.

A high level of both heavy and light industry and a higher proportion of public housing than Adelaide as a whole characterize Port Adelaide-Enfield. Much of the LGA was settled in the first half of the century, although most of the public housing was built in the postwar period. Mitcham was also settled in the first half of the century but is located in a more desirable part of Adelaide. Its land use is mostly residential, with some commercial districts and little light industry.

Although both areas have a relatively old age structure (in relation to Adelaide as a whole), they both have experienced substantial levels of gentrification over the last two decades. This is consistent with the character of the housing in the two areas—

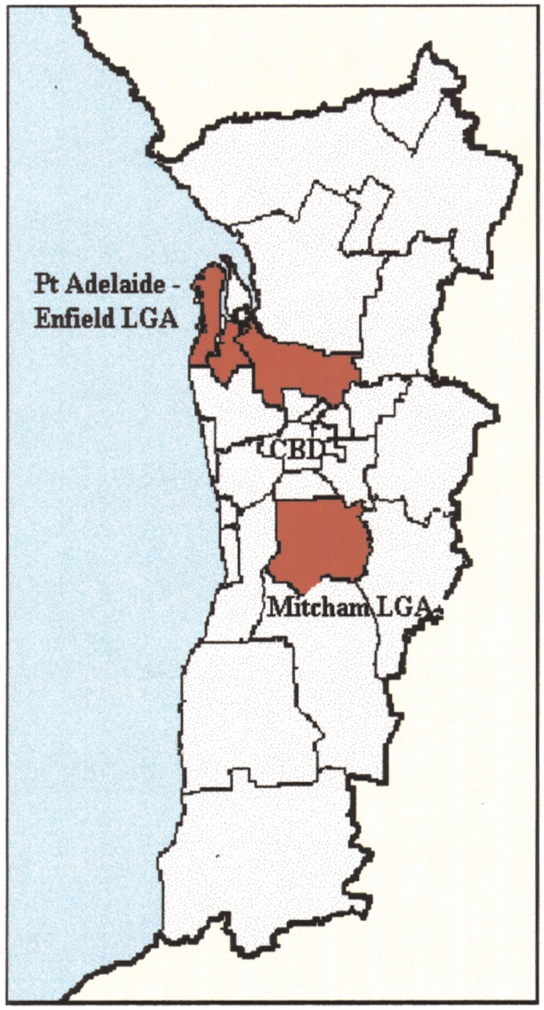

Figure 2 Location of case study areas in Adelaide, South Australia.

older-style cottages and bungalows have become popular and are increasingly in demand, particularly among higher-income professional households. However, the housing in Port Adelaide-Enfield is also low-priced and attractive to many low-income households, such as publicly housed households and some first-time home buyers.

Software and Hardware

ARC/INFO Version 7.1 (ESRI, Redlands, CA) was used on an IBM RS 6000 Unix workstation.

Datasets

Most of the risk factors identified in the literature are already represented in existing

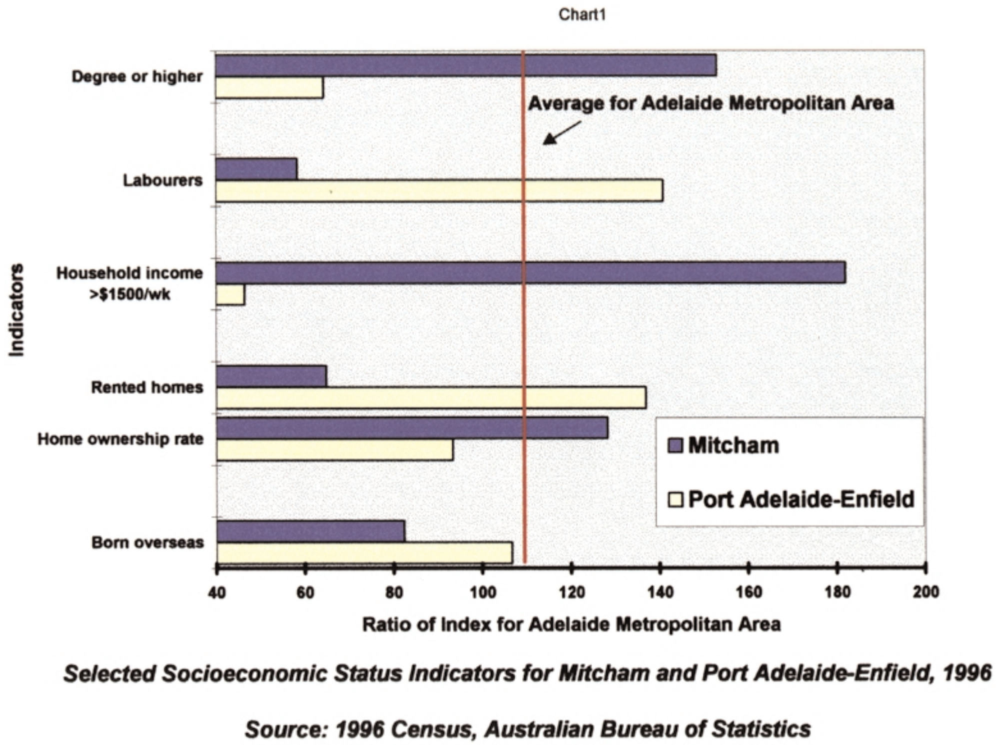

Figure 3 Selected socioeconomic status indicators for Mitcham and Port Adelaide-Enfield, Adelaide, South Australia, 1996.

datasets constructed for various other purposes. All that remains is to bring them together on a spatial basis. In this case, four main datasets were used.

The first is the Digital Cadastral Data Base (DCDB) for South Australia, which is a computer-based map of all land parcels in the state. It comprises approximately 800,000 land parcels, together with their legal identifiers. Associated data include street names and boundaries of administrative regions such as LGAs, wards, suburbs, hundreds, and counties. The South Australian DCDB is operated and maintained by the South Australian Department for Environment, Heritage and Aboriginal Affairs (DEHAA) but the location of the database varies from state to state. For example, there is no centralized DCDB in the state of Victoria—each local government in Victoria is responsible for the cadastre of its area.

The DCDB is widely used by government agencies and utility companies as a basic reference for land administration, local government administration, facilities management, planning, and asset management. It is one of the major core spatial datasets maintained by the government. Each parcel has a unique identifier that can be linked to property valuation assessments for rating and taxing purposes. It is the valuation data that provide a wealth of information pertaining to lead risk, namely:

- The dates on which properties were constructed

- The land use code for each parcel
- The material of dwellings' roofs and walls
- A rating of the condition of each dwelling on a scale of 1 to 9

The two case study LGAs represented 68,000 parcels, which reduced processing time and database management and storage considerably.

A second dataset used was the South Australian subset of the NSLIC. The original plan was to use it to validate the predictions of the GIS. However, the NSLIC proved to be somewhat disappointing for several reasons. One was that data on the ages of dwellings were based on either the interviewer's or the householder's estimates rather than on any reliable basis. Matching the addresses in the NSLIC with the valuation data and the DCDB showed that in 78% of cases, the year the householder or interviewer estimated the dwelling was built was incorrect, by a margin of approximately 5 years on average. Almost 90% of the households that were renting their houses made incorrect estimates of the year their dwelling was built, with an average error of 6 years. Most of these households lived in dwellings built before 1970. The degree of error generally increased with the age of the dwelling. The average size of the error was 10 years for dwellings built before 1920, 9 years for dwellings built between 1940 and 1960, 7 years for dwellings built between 1960 and 1970, 4 years between 1970 and 1980, and only 1.5 years for more recently built dwellings.

Another problem was the small number of cases—only 130 cases for the whole state. Only about half of those were located in Adelaide, even though Adelaide contains three-quarters of the state's population. No cases were located in Mitcham or Port Adelaide-Enfield. In terms of showing any geographical distribution of PbB, the number of cases was too small to draw any valid conclusions. Finally, some of the questions used in the household questionnaire were badly worded, the data on the condition of paint varied according to whether the householder or the interviewer estimated it, and the method of dust sample collection was not always appropriate.

Due to the continuing use of leaded gasoline in Australia, traffic flow rates were seen as an important indicator of lead risk for nearby residences. The South Australian Department of Roads and Transport supplied (at no charge) traffic information it had gathered of the whole state. Somewhat surprisingly, the electronic information they supplied did not include traffic counts associated with roads. Instead, they had hardcopy maps labeled with average daily number of vehicles for main roads. These had to be added to the GIS manually using the ArcEdit module of ARC/INFO. Traffic counts for suburban streets within the two case study LGAs were available from the respective local government engineering departments. The NSLIC defined a heavy traffic flow as 5,000 or more vehicles per day, which is very low. Thus it is not surprising that no correlation between PbB and proximity to roads was found in this study. However, when the same data were reanalyzed by the Victorian health department using traffic flows of greater than 20,000 vehicles per day, there was indeed an association. Consequently, the benchmark used in this study was 20,000 vehicles. Only 11 of the 133 cases in the South Australian subset of the NSLIC had data on traffic counts and only 7 of these were next to roads traveled by more than 20,000 vehicles per day.

The 1991 Census of Population and Housing (26) counts of the number of 0- to 4-year-olds were allocated to residential areas within the DCDB. Here we were forced to use averages to get around the problem of allocating areal data to individual dwellings.

Fortunately, the situation with Australian small-area census data is somewhat better than in the United States. Australia's smallest areal unit is the collector's district (CD), which contains 220 households on average, whereas the smallest American spatial unit, the block group, contains about 400 households. (By comparison, New Zealand's smallest unit is a "mesh block" of approximately 50 households and the United Kingdom's smallest unit contains around 170 households.)

We overlaid the CD boundaries with the DCDB and, for each CD, divided the number of children aged 0 to 4 by the number of residential dwellings shown in the DCDB. The resulting average number of children per dwelling was then allocated to every residential dwelling within the CD. In 1996, at the time of the most recent census, approximately 3,000 children aged 0 to 4 lived in Mitcham, forming 5% of the total population of that area. There were 6,300 children aged 0 to 4 in Port Adelaide-Enfield, forming 6.5% of the population. The percentage for the whole metropolitan area of Adelaide is 6.4%.

Results

Age

The two case study areas had similar proportions of housing built before 1970. Port Adelaide-Enfield had 81%, Mitcham 78%. This compares with 50% for Australia as a whole (27) and 53% for Adelaide (26,28). However, Mitcham has somewhat more housing built before 1952 (34%) than Port Adelaide-Enfield (28%). Clearly, we may expect most children in these LGAs to live in older housing; indeed, it was found that 1,200 Mitcham children under 5 (approximately 30%) and 1,150 Port Adelaide-Enfield children under 5 (approximately 27%) live in houses built before 1952. A further 30% of Mitcham children under 5 lived in houses built between 1952 and 1971, but around half of Port Adelaide-Enfield children under 5 lived in such housing. This is a reflection of the socioeconomic differences between the two LGAs. Figure 4 shows a view of the distribution of dwellings by age in part of Mitcham LGA.

Condition

According to our research, one-quarter of Mitcham dwellings are in bad condition. Approximately 800 children aged 0 to 4 live in these dwellings. However, only a quarter of bad-condition dwellings in Mitcham were built before 1952. This may reflect the level of gentrification in Mitcham—the older houses are very popular and tend to be quite valuable. In Port Adelaide-Enfield, 40% of housing was in bad condition, even though Mitcham and Port Adelaide-Enfield have similar proportions of housing built after 1952. Many of the bad-condition dwellings in Port Adelaide-Enfield were built after 1960; there, an estimated 2,500 children under 5 live in housing built after 1960.

Land Use

All land uses identified as possible lead risks were selected using the ARC/INFO commands reselect and the andselect, which were saved in an ARC Macro Language file (ARC Macro Language, or AML, is the macro language used within ARC/INFO). Based on the literature, "risk land uses" were defined as wholesale trade of petroleum products, service stations (gas stations), printing and allied industries, paint manufacturers,

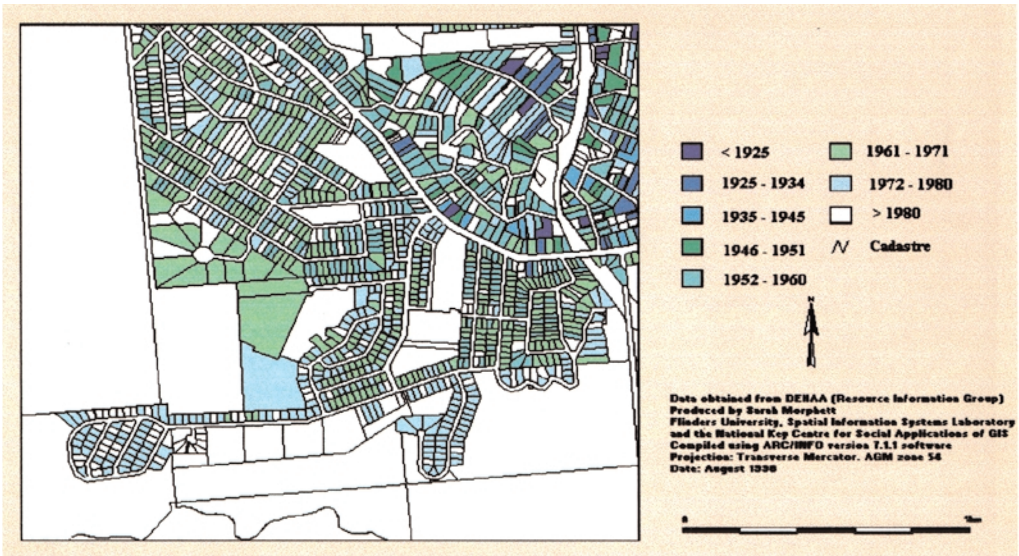

Figure 4 Detailed view of residential parcels by year built, Mitcham LGA.

petroleum refineries, petroleum and coal products, pottery, china and earthenware, iron and steel basic industries, non-ferrous metal industries, industrial waste disposal, active slag dumping and mineral waste disposal, and parking lots.

Port Adelaide-Enfield was found to have 255 risk land uses; there were actually 247 land parcels involved in risk land uses, but 5 of them were engaged in multiple risk land uses. The 247 parcels covered virtually the entire range of land uses identified in the literature, but the most important were service stations, printing industries, wholesale trade of gasolineeum products, and iron and steel basic industries.

Mitcham only had 28 risk land uses, and 23 of these were service stations. We found that approximately 20 children under 5 in Mitcham live within 50 meters of these land uses, while 135 children under 5 live in close proximity to risk land uses in Port Adelaide-Enfield.

Note that the buffer size was deliberately selected to be conservative because there is little discussion of buffers in the relevant literature to date. At this stage, the shape of the buffer is a simple circle with the land use as a point in the center, but we do acknowledge that a rose diagram with an ellipse-shaped buffer taking account of wind strength and direction would refine the buffering technique. It is emphasized that the aim was to keep the procedure as simple as possible with the option of refining the methodology later. Figure 5 shows the number of dwellings in close proximity to risk land uses.

Proximity to Busy Roads

The results from the NSLIC, limited as they are, showed that the average PbB for Adelaide children under 5 within 25 meters of roads with traffic counts of 20,000 or more was 0.35 µmol/dL, compared with 0.27 µmol/dL for those living on quieter streets. However, much previous research shows a strong link between PbB and traffic

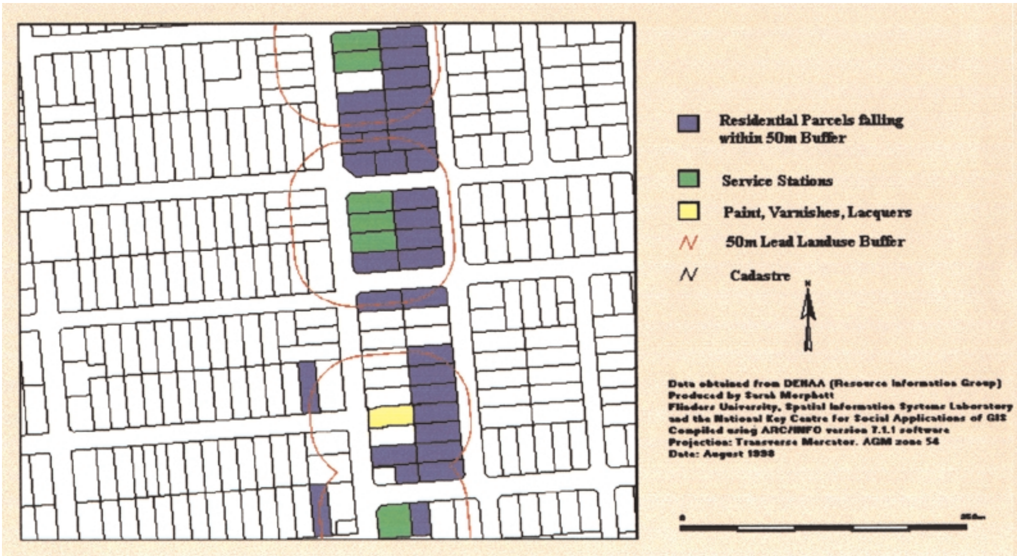

Figure 5 Detailed view of residential parcels adjacent to lead land use, Port Adelaide-Enfield LGA.

counts, so it is important to estimate how many children under 5 do live within 25 meters of major roads.

There were 117 children under 5 in Mitcham (4% of children under 5 in that LGA) within 25 meters of roads with average daily vehicle flow of 20,000 vehicles. The 25-meter buffer is measured from the center of the road. Road widths vary; the Department of Transport traffic data do contain information on road widths, so it is possible to increase the size of the buffer according to the width of the road. However, for the sake of simplicity and to construct a basic model, we used a 25-meter buffer on all roads regardless of their width. Note that the NSLIC did not adjust distances from roads according to road widths (which of course reflect traffic flows). This means that the number of children in close proximity to major roads as calculated here is a conservative figure. Figure 6 shows the number of residential parcels in close proximity to busy roads in Mitcham LGA.

Even though the number of children under 5 in Port Adelaide-Enfield is double that of Mitcham, only 151 children under 5 in that LGA (2%; i.e., proportionally half as many) live within 25 meters of roads carrying more than 20,000 vehicles per day. This proportion is smaller for Port Adelaide-Enfield than for Mitcham because there are more industrial and commercial facilities than residential properties along the heavy-traffic roads in Port Adelaide-Enfield.

In sum, it is estimated that more than 4,000 children under 5 (approximately 40% of the population of 0- to 4-year-olds) in the two case study areas are possibly exposed to lead risk factors. The two most common risk factors found together are old housing and poor housing condition; these two risk factors are present for over 90% of dwellings in the two case study areas. The relative importance of each risk factor is similar in both case study areas, although traffic is more important for Mitcham, while risk land uses

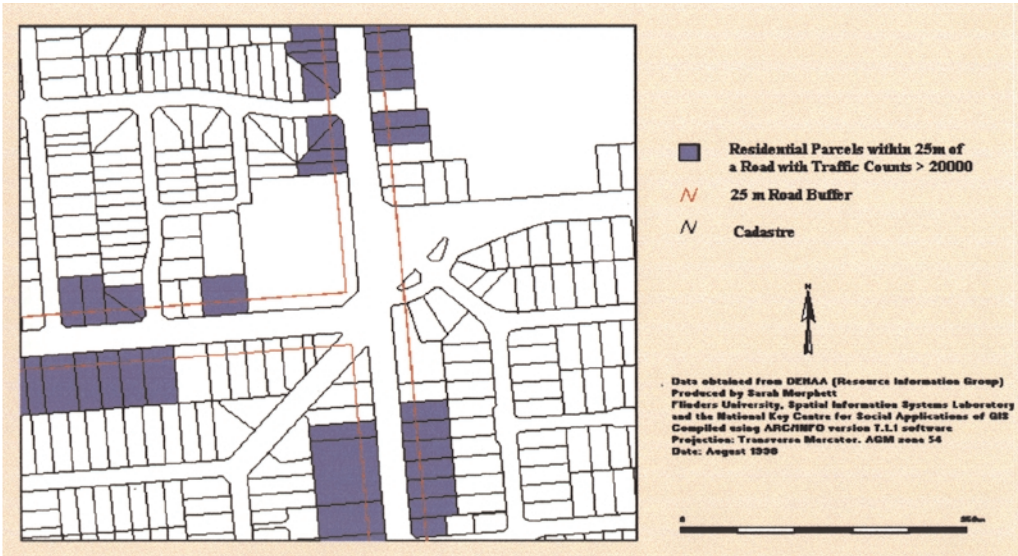

Figure 6 Detailed view of residential parcels adjacent to high traffic counts, Port Adelaide-Enfield LGA.

are more common in Port Adelaide-Enfield. Figure 7 shows a selected portion of Mitcham dwellings identified with at least one risk factor.

Discussion and Conclusion

Validity of Methods

The validity of the GIS' predictions as to which areas and dwellings may be classified as high-risk or low-risk in terms of the presence or absence of lead risk factors is currently being tested using dust sample analysis. Dwellings were divided into three risk categories based on the number of lead risk factors present—none, one or two, or more, corresponding to no, moderate, and high risk. Approximately 100 addresses from each group were randomly selected and letters were sent requesting assistance in the research. Unfortunately, the response rate has been poor, around 20%. Much of this is related to the elderly age structure of the two case study areas—many of the householders felt that the study was not relevant to them, while many others undoubtedly had security concerns. This was not helped by media reports of bogus charity collectors and similar scams, which were prominent at the time the survey was conducted.

Limitations

The most obvious limitation is the lack of data on the actual addresses of the target population (i.e., children under 5). Confidentiality concerns mean that all identifying information collected by the Australian Bureau of Statistics for the Census is destroyed. In addition, these data are only collected once every five years (although this is a distinct advantage over American Census data, collected every 10 years). However, it may be

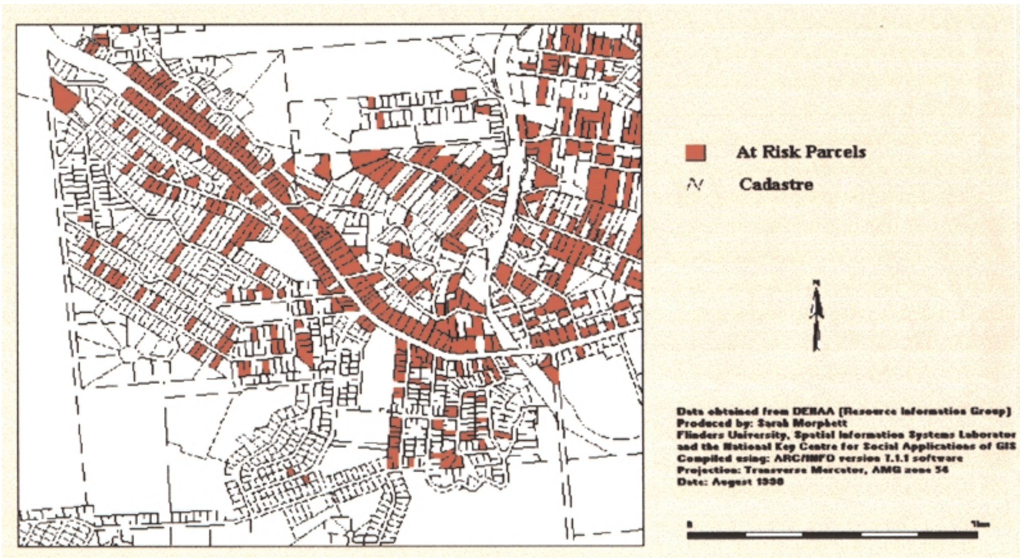

Figure 7 Detailed view of all risk factors, Mitcham LGA.

possible to obtain the addresses of young children via the records for immunization for childhood diseases held by local governments and other organizations.

Another limitation is the use of dust samples in a dwelling as an indicator of PbB. The literature is divided over the utility of dust as an indicator; however, circumstances are such that while the value of blood sampling is appreciated, dust sampling is the only viable alternative. The United States is fortunate in its access to good data on PbB.

The lead risk model presented here is the first step in developing a lead risk model for Adelaide and other urban centers in South Australia. It can be refined by weighting the factors and incorporating other parameters such as wind direction and strength, presence of traffic lights (because the presence of stationary traffic is an important factor in airborne lead [5]), historical land use data, materials of roofs and walls, and road widths. Even in its present form, this model would greatly improve the efficiency of any expenditure on lead as a health problem. The model makes it possible to mail information to specific households, rather than all households. Obviously, we cannot neglect the role of risk factors beyond the domain of GIS, such as the cleanliness of homes and the occupations and hobbies of parents. But the use of GIS in lead prevention programs offers a great deal in terms of targeting of environmental lead factors. This is at least half the battle.

Acknowledgments

I would like to thank Steve Fildes, Sarah Morphett, and David Schroeder of the Spatial Information Systems Laboratory in the School of Geography, Population and Environmental Management at Flinders University for their research assistance and technical assistance with this project.

References

1. Baker NJ de C. 1995. A 13 year review of childhood lead poisoning in Christchurch and Nelson. *New Zealand Medical Journal* 108(1002):249–51.
2. Graef JW. 1997. Foreword. In: *Getting the lead out.* Ed. I Kessel, JT O'Connor. New York: Plenum Press.
3. Donovan J. 1996. No lead is good lead. *Medical Journal of Australia* 64(7):390–1.
4. Nur Ahmed, Australian Institute of Petroleum. 1998. Personal communication (telephone and e-mail). May 11–12.
5. Alder RJ, Dillon JA, Loomer S, Poon HC, Robertson JM. 1993. An analysis of blood lead data in clinical records by external data on lead pipes and age of household. *Journal of Exposure Analysis and Environmental Epidemiology* 3(3):299–314.
6. Donovan J. 1996. *Lead in Australian children: Report on the National Survey of Lead in Children.* Canberra, Australia: Australian Institute of Health and Welfare.
7. Gulson BL, Mizon KJ, Korsch MJ, Howarth D. 1996. Importance of monitoring family members in establishing sources and pathways of lead in blood. *Science of the Total Environment* 188(2–3):173–82.
8. Gulson BL, Davis JJ, Bawden-Smith J. 1995. Paint as a source of recontamination of houses in urban environments and its role in maintaining elevated blood leads in children. *Science of the Total Environment* 164(3):221–35.
9. Brody DJ, Pirkle JL, Kramer RA, Flegal KM, Matte TD, Gunter EW, Paschal DC. 1994. Blood lead levels in the US population. Phase 1 of the Third National Health and Nutrition Examination Survey. *Journal of the American Medical Association* 272(4):277–83.
10. Mira M, Bawden-Smith J, Causer J, Alperstein G, Karr M, Snitch P, Waller G, Fett MJ. 1996. Blood lead concentrations of preschool children in central and southern Sydney. *Medical Journal of Australia* 164(7):399–402.
11. Willis FR, Rossi E, Bulsara M, Slattery MJ. 1995. The Fremantle lead study. *Journal of Paediatrics and Child Health* 31(4):326–31.
12. Rosen JF. 1995. Adverse health effects of lead at low exposure levels: Trends in the management of childhood lead poisoning. *Toxicology* 97(1–3):11–7.
13. Casey R, Wiley C, Rutstein R, Pinto-Martin J. 1994. Prevalence of lead poisoning in an urban cohort of infants with high socioeconomic status. *Clinical Pediatrics* 33(8):480–4.
14. Sargent JD, Brown MJ, Freeman JL, Bailey A, Goodman D, Freeman DH Jr. 1995. Childhood lead poisoning in Massachusetts communities: Its association with sociodemographic and housing characteristics. *American Journal of Public Health* 85(4):528–34.
15. France EK, Gitterman BA, Melinkovich P, Wright RA. 1996. The accuracy of a lead questionnaire in predicting elevated pediatric blood lead levels. *Archives of Pediatrics and Adolescent Medicine* 150(9):958–63.
16. Schaffer SJ, Kincaid MS, Endres N, Weitzman M. 1996. Lead poisoning risk determination in a rural setting. *Pediatrics* 97(1):84–90.
17. Snyder DC, Mohle-Boetani JC, Palla B, Fenstersheib M. 1995. Development of a population-specific risk assessment to predict elevated blood lead levels in Santa Clara County, California. *Pediatrics* 96(4 Part 1):643–8.
18. Threlfall T, Kent N, Garcia-Webb P, Byrnes E, Psaila-Savona P. 1993. Blood lead levels in children in Perth, Western Australia. *Australian Journal of Public Health* 17(4):379–81.

19. Edwards-Bert P, Calder IC, Maynard EJ. 1993. *National review of public exposure to lead in Australia.* Adelaide, South Australia: South Australian Health Commission.

20. Guthe WG, Tucker RK, Murphy EA, England R, Stevenson E, Luckhardt JC. 1992. Reassessment of lead exposure in New Jersey using GIS technology. *Environmental Research* 59(2):318–25.

21. Hanchette C. 1994. *GIS modeling of lead poisoning risk factors.* Paper presented at the Second Comprehensive National Conference on Building a Lead-Safe Future. May 16–18, 1994. Washington, DC.

22. Hanchette C. 1997. A predictive model of lead poisoning risk in North Carolina: Validation and evaluation. In: *Proceedings of the International Symposium on Computer Mapping in Epidemiology and Environmental Health.* Ed. RT Aangeenbrug, PE Leaverton, TJ Mason. Alexandria, VA: World Computer Graphics Foundation.

23. Padgett DA. 1997. Geographic information systems techniques for delineating hot spots of childhood lead-soil exposure sources. In: *Proceedings of the International Symposium on Computer Mapping in Epidemiology and Environmental Health.* Ed. RT Aangeenbrug, PE Leaverton, TJ Mason. Alexandria, VA: World Computer Graphics Foundation.

24. Wartenburg D. 1992. Screening for lead exposure using a GIS. *Environmental Research* 59:310–7.

25. Covello VT, Merkhofer MW. 1993. *Risk assessment methods: Approaches for assessing health and environmental risks.* New York: Plenum Press.

26. Australian Bureau of Statistics. 1991. *1991 census of population and housing.* Belconnen, Australian Capital Territory: Australian Bureau of Statistics.

27. Berry M. 1994. *Reducing lead exposure in Australia.* Commonwealth Department of Human Services and Health. Canberra, Australia: Australian Government Publishing Service.

28. Department of Environment and Natural Resources (DENR). 1997. *1997 digital cadastre database.* Adelaide, Australia: DENR.